Cerebrospinal fluid drainage reduces paraplegia after thoracoabdominal aortic aneurysm repair: Results of a randomized clinical trial

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Objective: **Despite the use of various strategies for the prevention of spinal cord ischemia, paraplegia and paraparesis continue to occur after thoracoabdominal aortic aneurysm (TAAA) repair. Although cerebrospinal fluid drainage (CSFD) is often used as an adjunct for spinal cord protection, its benefit remains unproven. The purpose of this randomized clinical trial was to evaluate the impact of CSFD on the incidence of spinal cord injury after extensive TAAA repair.**

Methods: **After randomization, 145 patients underwent extent I or II TAAA repairs with a consistent strategy of moderate heparinization, permissive mild hypothermia, left heart bypass, and reattachment of patent critical intercostal arteries. The repairs were performed with CSFD (n = 76) or without CSFD (n = 69). In the former group, CSFD was initiated during the operation and continued for 48 hours after surgery. The target CSF pressure was 10 mm Hg or less.**

Results: **The two groups had similar risk factors for paraplegia. Aortic clamp time, left heart bypass time, and number of reattached intercostal arteries were also similar in both groups. Thirty-day mortality rates were 5.3% (four patients) and 2.9% (two patients) for CSFD and control groups, respectively (P = .68). Nine patients (13.0%) in the control group had paraplegia or paraparesis develop. In contrast, only two patients in the CSFD group (2.6%) had deficits develop (P = .03). No patients with CSFD had immediate paraplegia. Overall, CSFD resulted in an 80% reduction in the relative risk of postoperative deficits.**

Conclusion: **Perioperative CSFD reduces the rate of paraplegia after repair of extent I and II TAAAs. (J Vasc Surg 2002;35;631-9.)**

Ischemic spinal cord injury after thoracoabdominal aortic aneurysm (TAAA) repair remains a devastating complication. In addition to the inherent physical disability, patients with postoperative paraplegia and paraparesis have decreased survival rates.[1] Neurologic outcome is influenced by aneurysm extent, acute dissection, increasing cross-clamp times, preoperative renal dysfunction, previous aortic surgery, diabetes, and rupture.[1-6] The variety of adjuncts currently used, which include generalized[7] and local hypothermia,[8] medications such as steroids,[9] naloxone hydrochloride,[10,11] barbiturates,[12] and papaverine hydrochloride,[13] reattachment of intercostal arteries,[14] and cerebrospinal fluid drainage (CSFD),[15,16] is testimony to the fact that no method has been universally effective in prevention of paraplegia.

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Although CSFD is often used as a protective adjunct against spinal cord ischemia, its benefit remains unproven. Several retrospective studies suggest a benefit but are difficult to interpret because of confounding factors.[11,15-17] Previous randomized clinical trials have reported conflicting results.[13,18] The purpose of this study was to evaluate the impact of CSFD on the incidence of spinal cord injury after extensive TAAA repair.

METHODS

Study design. The protocol was approved by Baylor College of Medicine's Institutional Review Board. After a randomization sequence was generated with a computer, assignments (repair with or without CSFD) were placed into sequentially numbered opaque envelopes. Only patients who underwent planned repair of extensive TAAAs (Crawford extent I or II[19]) were eligible. Preoperative exclusion criteria included previous TAAA surgery, shock, and contraindications to spinal catheter placement. A sealed randomization envelope was opened immediately before operation in patients without preoperative exclusion criteria. The surgical team was not blinded to group assignment. All randomized patients were followed in accordance with intention-to-treat principles.

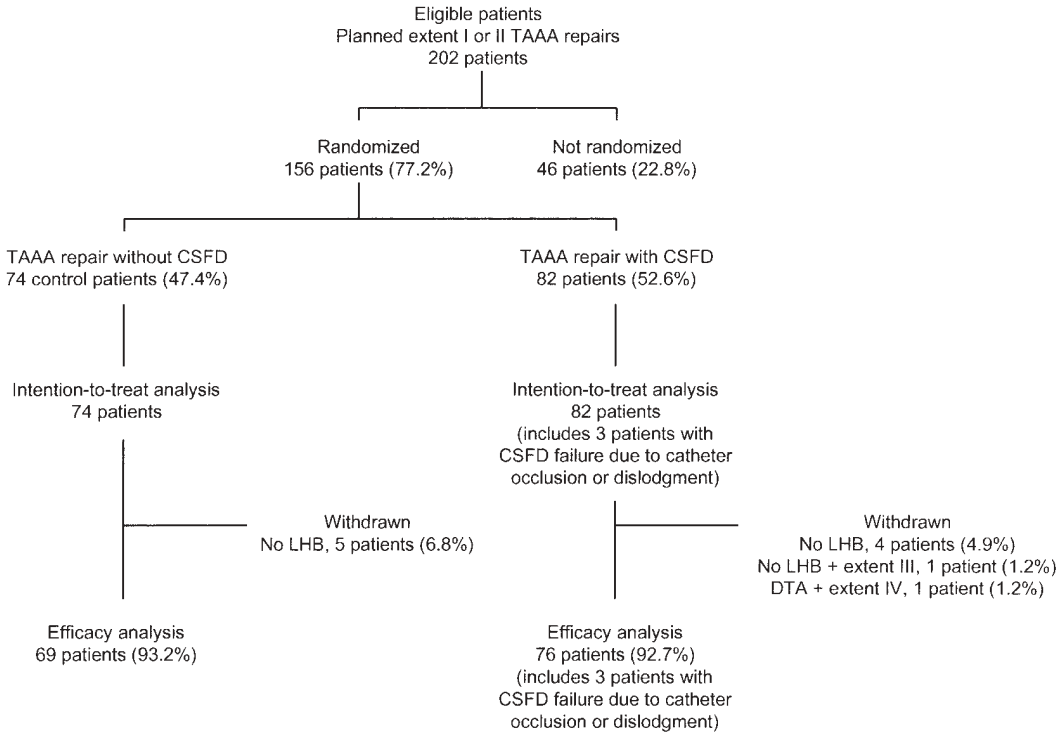

Fig 1. Diagram shows trial profile, including participant flow after randomization, patient availability for intention-to-treat analysis, and withdrawals for secondary efficacy analysis. *TAAA,* Thoracoabdominal aortic aneurysm; *CSFD,* cerebrospinal fluid drainage; *LHB,* left heart bypass; *DTA,* descending thoracic aortic aneurysm.

For the study to be focused on a single treatment variable (CSFD) in patients who underwent extensive TAAA repairs, the following two secondary intraoperative exclusion criteria were defined a priori: 1, inability to use left heart bypass (LHB); and 2, performance of a less extensive repair (extent III or IV) than planned. The study endpoints were death, paraplegia, and paraparesis.

Patients. The planned total enrollment was 184 patients. Between May 29, 1997, and April 1, 1999, 308 patients underwent TAAA repair. Of these, 202 consecutive patients (65.6%) were eligible on the basis of a planned extent I or II TAAA repair (Fig 1). Forty-six patients (22.8%) were not randomized because of previous TAAA operation, preoperative shock, patient decision against participation, contraindications to spinal catheter placement (coagulopathy, prior back surgery, etc), or logistic issues. Ultimately, 156 patients (77.2%) met the study criteria and were randomized after written informed consent was obtained: 74 patients (47.4%) were randomized to the control group and 82 patients (52.6%) were randomized to CSFD. Interim analysis results after the enrollment of 156 patients showed significant differences, and therefore the study was halted.

Operative technique. All patients underwent graft repair with standardized techniques and a consistent strategy for spinal cord protection: LHB, moderate heparinization, permissive mild hypothermia, and aggressive reattachment of available critical intercostal and lumbar arteries (thoracic vertebrae 7 [T7] to lumbar vertebrae 2 [L2]).[20-22] The experimental group underwent CSFD in addition to these adjuncts.

The aorta was exposed with a left thoracoabdominal incision and circumferential division of the diaphragm. After moderate systemic heparinization (1 mg/kg), LHB was established with cannulae inserted into the left inferior pulmonary vein and the distal descending thoracic aorta; the bypass circuit did not include an oxygenator or heat exchanger. Nasopharyngeal temperature was allowed to drift to 32°C to 33°C. Depending on the proximal extent of the aneurysm, an aortic clamp was placed either proximal or distal to the left subclavian artery. After placement of a second aortic cross-clamp between T4 and T7, the segment of aorta between the clamps was opened. Patent intercostal arteries within this proximal segment were oversewn. After completion of the proximal anastomosis, LHB was discontinued, the distal clamp was removed, and the remaining aneurysm was opened longitudinally. In patients who underwent extent II repairs, balloon perfusion catheters were positioned within the origins of the celiac, superior mesenteric, and renal arteries for selective visceral perfusion delivered from the LHB circuit. Whenever possible, patent segmental arteries between T7 and L2 were reattached to the graft. The visceral and renal arteries were reattached with either a beveled open distal anastomosis (extent I) or inclusion patch (extent II). After reattachment of the visceral and renal vessels in extent II

Table I. Comparison of preoperative characteristics for patients who underwent thoracoabdominal aortic aneurysm repair with and without cerebrospinal fluid drainage

Variable	*CSFD (n = 76)*	*Control (n = 69)*	P *value*
Age (years)	65.5 ± 10.2	65.5 ± 10.9	.99
Male/female	46/30	44/25	.73
Hypertension	62 (81.6%)	54 (78.3%)	.68
Chronic obstructive pulmonary disease*	12 (15.8%)	16 (23.2%)	.30
Renal failure†	4 (5.3%)	4 (5.8%)	1.0
Diabetes mellitus	3 (3.9%)	3 (4.3%)	1.0
Marfan syndrome	4 (5.3%)	5 (7.2%)	.74
FEV_1 (% of predicted)	73.6 ± 19.2	68.9 ± 18.1	.23
Left ventricular ejection fraction	60.0% ± 11.2%	59.4% ± 12.8%	.80
Active smoker	47 (61.8%)	45 (65.2%)	.73
Preoperative creatinine level			
<1.5 mg/dL	58 (78.4%)	58 (84.1%)	.40
1.5 to 2.0 mg/dL	11 (14.9%)	8 (11.6%)	.63
>2 mg/dL	5 (6.8%)	3 (4.3%)	.72
Cause of aneurysm			
MDD	46 (60.5%)	39 (56.5%)	.74
Chronic dissection	25 (32.9%)	25 (36.2%)	.73
Acute dissection	4 (5.3%)	1 (1.4%)	.40
MDD + superimposed acute dissection	0	1 (1.4%)	.48
MDD + superimposed chronic dissection	1 (1.3%)	3 (4.3%)	.35
Symptoms			
No symptoms	16 (23.5%)	23 (35.4%)	.18
Mild symptoms	36 (52.9%)	35 (53.8%)	1.0
Severe pain	16 (23.5%)	7 (10.8%)	.07
Acute presentation‡	6 (7.9%)	4 (5.8%)	.75
Aneurysm extent			
I	32 (42.1%)	33 (47.8%)	.51
II	44 (57.9%)	36 (52.2%)	.51
Previous aortic surgery			
Ascending aortic aneurysm repair	12 (15.8%)	11 (15.9%)	1.0
Aortic arch surgery	10 (13.2%)	10 (14.5%)	1.0
Abdominal aortic aneurysm repair	19 (25.0%)	8 (11.6%)	.05
Predicted rate of paraplegia or paraparesis[11]	26 (34.2%)	24 (34.8%)	1.0

Continuous variables are presented as mean ± standard deviation.
*Chronic obstructive pulmonary disease was defined as requirement of pharmacologic therapy for treatment of chronic pulmonary compromise or forced expiratory volume in 1 second of less than 75% of predicted value.
†Renal failure was defined as serum creatinine level of 3.0 mg/dL or more or need for hemodialysis.
‡Acute presentation included acute pain, rupture, contained rupture, and complicated acute dissection.[10,11]
FEV_1, Forced expiratory volume in 1 second; *MDD,* medial degenerative disease.

repairs, the balloon catheters were removed; whenever possible, the clamp was replaced below the renal arteries to provide intercostal and visceral/renal perfusion during the open distal aortic anastomosis. Hypotension after cross-clamp removal was avoided with vigorous volume replacement and, when necessary, intravenous inotropes or pressors. The operative field was irrigated with warm saline solution after completion of all anastomoses. No other means of rewarming the patient were used during the operation. Warm air blankets (Bair Hugger, Augustine Medical, Inc, Eden Prairie, Minn) were used after surgery.

Cerebrospinal fluid drainage. Patients randomized to undergo CSFD were placed in right lateral decubitus position, and a 5F silicone lumbar catheter (Elekta Instruments, Inc, Atlanta, Ga) was introduced into the subarachnoid space at the L3 or L4 intervertebral space via a Tuohy needle. The catheter was connected to a pressure transducer and a drainage set that included a 75-mL graduated cylinder and a 500-mL drainage bag (Elekta Instruments, Inc). The transducer's zero point was set while level with the patient's spine. The CSF pressure was monitored continuously during surgery and the early postoperative period. Cerebrospinal fluid was allowed to freely drain with gravity whenever CSF pressure exceeded 10 mm Hg. In patients without a spinal cord deficit, the drain was removed on postoperative day 2. In the presence of neurologic injury, however, the catheter was kept in place beyond 2 days.

Neurologic evaluation. Each patient's neurologic status was evaluated daily until discharge and was classified as "deficit" or "no deficit." Lower extremity motor function was assessed by either asking the patient to alternately raise each leg off of the bed (early after operation) or observing ambulation (later). Deficits were scored as described by Crawford et al[18]: 1, minimal or no motion; 2, motion but not against resistance or gravity; 3, motion against resistance and gravity but no ability to stand or walk; and 4, ability to stand and walk with assistance. Deficit scores during the initial postoperative course were

Table II. Comparison of operative and postoperative variables for patients who underwent thoracoabdominal aortic aneurysm repair with and without cerebrospinal fluid drainage

Variable	*CSFD (n = 76)*	*Control (n = 69)*	P *value*
Left heart bypass time (minutes)	21.0 ± 6.9	22.0 ± 6.9	.35
Cross-clamp and ischemic times* (minutes)			
Total aortic clamp time	53.8 ± 15.3	55.1 ± 16.2	.62
Total unprotected aortic clamp time	34.6 ± 13.9	34.8 ± 13.6	.91
Intercostal ischemic time	46.3 ± 12.2	47.4 ± 12.0	.56
Unprotected intercostal ischemic time	26.9 ± 10.6	27.3 ± 8.5	.82
Visceral ischemic time	48.7 ± 14.0	48.8 ± 12.7	.95
Unprotected visceral ischemic time	23.1 ± 13.7	24.3 ± 11.4	.57
Body temperature before cross-clamping (°C)	34.9 ± 5.0	34.4 ± 1.1	.59
Body temperature after declamping (°C)	32.7 ± 0.8	32.9 ± 0.9	.29
Total reattached intercostal arteries (pairs)	2.3 ± 0.9	2.3 ± 1.0	.91
Patients without intercostal reattachment	2 (2.6%)	4 (5.8%)	.42
Patients with reattached intercostal arteries			
T6	1 (1.3%)	0	1.0
T7	1 (1.3%)	2 (2.9%)	.60
T8	14 (18.4%)	11 (15.9%)	.83
T9	32 (42.1%)	33 (47.8%)	.51
T10	55 (72.4%)	50 (72.5%)	1.0
T11	43 (56.6%)	38 (55.1%)	.87
T12	27 (35.5%)	18 (26.1%)	.28
Lumbar	0	2 (2.9%)	.22
Intercostal endarterectomy and reattachment	2 (2.6%)	1 (1.4%)	1.0
Intercostal artery bypass from aortic graft	1 (1.3%)	0	1.0
Bifurcated graft for iliac revascularization	5 (6.6%)	2 (2.9%)	.45
Intraoperative hypotension (MAP <60 mm Hg)	13 (17.1%)	11 (15.9%)	1.0
Postoperative hypotension (MAP <70 mm Hg)	31 (40.8%)	19 (27.5%)	.12
Transfusion (units)			
Cell saver	18.1 ± 13.7	16.8 ± 10.6	.55
Packed red blood cells	3.1 ± 1.9	3.2 ± 2.0	.77
Platelets	6.6 ± 9.0	5.2 ± 7.9	.33
Fresh frozen plasma	7.1 ± 9.4	6.9 ± 8.9	.86
Cryoprecipitate	0.9 ± 5.2	1.2 ± 5.9	.74

*Unprotected clamp and ischemic times were calculated with subtraction of left heart bypass time from clamp or ischemic time in question.
CSFD, Cerebrospinal fluid drainage; *T,* thoracic vertebrae; *MAP,* mean arterial pressure.

restricted to 1 to 3 because ambulation could not be tested until clinically appropriate. For each patient with a deficit, the worst (lowest) score was used to categorize the deficit as paraplegia (scores of 1 or 2) or paraparesis (3 or 4). All deficits were scored and categorized, regardless of the degree or rate of any subsequent improvement. Neurologic deficits present on awakening from anesthesia were classified as immediate; deficits that occurred after previously normal postoperative examination were classified as delayed. Unilateral lower extremity deficits were attributed to spinal cord injury unless an associated deficit involving the ipsilateral upper extremity—indicating a stroke—was present.

Statistical analysis. After performance of an intention-to-treat analysis that included all randomized patients, an efficacy analysis was performed. In this secondary analysis, any patient in whom LHB could not be used was withdrawn to eliminate LHB as a variable. Patients who did not undergo extent I or II repair because of intraoperative findings were also excluded from the secondary analysis. The efficacy analysis, therefore, focused solely on extent I and II repairs completed with LHB.

The statistical analysis was performed with the SAS system for Windows (release 6.10; SAS Institute, Inc, Cary, NC). Comparisons between the CSFD and control patient groups were performed with the Fisher exact test for categoric variables and the Student *t* test for continuous variables. Associations between aortic clamp time, CSFD, and the risk of paraplegia were further analyzed with logistic regression curves. *P* values of less than .05 were considered statistically significant. Continuous values were reported as mean ± standard deviation.

RESULTS

Intention-to-treat analysis. Paraplegia or paraparesis occurred in nine of 74 patients (12.2%) in the control group versus two of 82 patients (2.7%) who underwent CSFD ($P = .03$). The overall operative mortality rate[23] was 7.1% (11 of 156), which included six deaths within 30 days (range, 5 to 24 days) and five subsequent deaths in hospital (range, 33 to 140 days). All patients survived long enough to undergo neurologic assessment. Thirty-day mortality rates for patients in the control and CSFD groups were 2.7% (2/74) and 4.9% (4/82), respectively ($P = .68$). In-hospital mortality rates were also similar in both groups: 6.8% (5/74) for patients in the control group and 7.3% (6/82) for patients in the CSFD group ($P = 1.0$).

Table III. Characteristics of patients in whom paraplegia or paraparesis developed after thoracoabdominal aortic aneurysm repair

Group	*Extent of repair*	*Timing of injury*	*Degree of injury*	*Initial postoperative score*	*Postoperative CSFD*	*Final score*	*Outcome*
Control	II	Immediate	Paraplegia	1	Yes	1	Death
Control	II*	Immediate	Paraplegia	1	Yes	1	No improvement
Control	II	Immediate	Paraplegia	2	Yes	4	Improved
Control	II	Immediate	Paraplegia	2	Yes	4	Improved
Control	I	Immediate	Paraplegia	2	Yes	L, 2; R, 4	Death
Control	II	Immediate	Paraplegia	1	Yes	3	Death
Control	II	Immediate	Paraparesis	3	Yes	3	Death
Control	II	Delayed	Paraparesis	3	No	4	Improved
Control	II*	Delayed	Paraplegia	2	Yes	2	No improvement
CSFD	I	Immediate	Paraparesis	3	Yes	4	Death
CSFD	I	Delayed	Paraplegia	1	Yes	1	No improvement

*Aortic clamp placed proximal to left subclavian artery.
CSFD, Cerebrospinal fluid drainage; *L,* left; *R,* right.

Table IV. Postoperative lower extremity neurologic deficits after repair of extensive thoracoabdominal aortic aneurysms

Neurologic injury	*CSFD (n = 76)*	*Control (n = 69)*	P *value*	*Risk reduction*	
				Absolute	*Relative*
All lower extremity neurologic deficits	2 (2.6%)	9 (13.0%)	.03	10.4%	80%
Immediate neurologic deficits	1 (1.3%)	7 (10.1%)	.03	8.8%	87.1%
Paraplegia	0	6 (8.7%)	.01	8.7%	100%
Paraparesis	1 (1.3%)	1 (1.4%)	1.0		
Delayed neurologic deficits	1 (1.3%)	2 (2.9%)	.60		
Paraplegia	1 (1.3%)	1 (1.4%)	1.0		
Paraparesis	0	1 (1.4%)	.48		

CSFD, Cerebrospinal fluid drainage.

Efficacy analysis. For sole focus on extent I and II repairs completed with LHB, which left CSFD as the only treatment variable, the secondary efficacy analysis was performed after the elimination of the 11 patients who met intraoperative exclusion criteria (Fig 1). Five patients in each group were withdrawn because of an intraoperative decision not to use LHB; this was generally because of an inability to safely clamp the mid-descending thoracic aorta. In two patients in the CSFD group, extent II repairs were planned, but lesser resections were performed on the basis of intraoperative findings; both patients were withdrawn. All 11 patients who were withdrawn survived without deficits. Ultimately, 69 patients in the control group and 76 patients in the CSFD group were entered into the efficacy analysis detailed subsequently.

Comparison of preoperative and intraoperative factors. There were no significant differences in preoperative characteristics between the two groups (Table I). There were trends toward more patients with severe pain and previous abdominal aortic aneurysm repair in the CSFD group. More importantly, the distributions of TAAA extents, aortic dissection, and acute presentation—well-established risk factors for spinal cord injury after TAAA repair—were similar in the two groups. Acher et al's[11] predictive formula for paraplegia and paraparesis was applied to each group; this model showed that the two groups were at similar overall risk for neurologic deficits. Similarly, there were no significant differences between intraoperative variables, including clamp and ischemic times, body temperatures, and reattachment of intercostal arteries (Table II).

Cerebrospinal fluid drainage. In the CSFD group, 64.1 ± 42.9 mL of CSF (range, 10 to 250 mL) were drained during surgery and 260.9 ± 190.5 mL of CSF (range, 40 to 864 mL) were drained during the postoperative period. In two patients, the CSFD catheter became occluded during surgery. One CSFD catheter became dislodged while the patient was transported to the intensive care unit. These three catheters were not replaced. There were no other complications (eg, CSF leak or catheter infection) related to the CSFD protocol. In all patients with functioning spinal catheters, CSF pressure was maintained at 10 mm Hg or less.

Neurologic deficit. The characteristics of each patient with a deficit are detailed in Table III. Eight of nine patients in the control group who had deficits had CSFD catheters placed after the deficit developed. Having reached the study endpoint (paraplegia or paraparesis), the patients remained in the control group for all analyses. Rapid neurologic improvement did not occur after catheter insertion in any of these eight patients. All three patients with malfunctioning or dislodged CSFD catheters

Table V. Subgroup analysis of variables examined for association with immediate postoperative paraplegia

Variable	*Without immediate postoperative paraplegia (n = 139)*	*With immediate postoperative paraplegia (n = 6)*	P *value*
Surgery without cerebrospinal fluid drainage	63 (45.3%)	6 (100.0%)	.01
Total unprotected aortic clamp time* (minutes)	34.2 ± 13.5	48.8 ± 12.8	.03
Total aortic clamp time (minutes)	53.8 ± 15.6	67.3 ± 11.3	.04

*Total unprotected aortic clamp time was calculated with subtraction of left heart bypass time from total aortic clamp time.

survived without deficits. On the basis of the intention-to-treat principle, these three patients remained in the CSFD group for all analyses.

Neurologic injuries developed in two patients in the CSFD group (2.6%) and in nine patients in the control group (13.0%; $P = .026$). This corresponds to an 80% reduction in the relative risk of paraplegia or paraparesis. Logistic regression curves show that the longer the ischemic times were, the greater the benefit afforded with CSFD (Fig 2). CSFD reduced immediate deficits, particularly paraplegia (Table IV). One patient in the CSFD group (1.3%) had immediate moderate paraparesis involving the left lower extremity; this patient's condition improved substantially within 2 weeks, and the patient was ultimately able to walk with assistance. In contrast, seven patients in the control group had immediate neurologic deficits (10.1%; $P = .03$). Delayed neurologic deficits were infrequent in both groups. The single delayed deficit that occurred in a patient in the CSFD group manifested immediately after a period of atrial fibrillation and hypotension on postoperative day 1; this resulted in permanent paraplegia.

The volume of CSF drained during surgery was not different between patients with and without neurologic injury (64.1 ± 5.2 mL versus 62.5 ± 12.5 mL, respectively; $P = .96$). The average duration of spinal catheter drainage was 77 ± 5 hours and 42.7 ± 1.8 hours for patients with and without neurologic injury, respectively ($P = .003$). The extended period of CSFD in the two patients in whom deficits developed resulted in an increase in the amount of postoperative drainage (533.3 ± 120 mL) compared with the amount drained from the patients without neurologic injury (250.0 ± 21.5 mL; $P = .01$).

In nine of 11 patients with deficits (81.8%), the aortic clamp was placed distal to the left subclavian artery. The clamp was initially positioned proximal to the left subclavian artery in two patients with deficits; both were in the control group (Table III).

With the strong association between immediate paraplegia and surgery without CSFD, a subgroup analysis regarding risk factors for immediate paraplegia was performed (Table V). In addition to surgery without CSFD, only two factors were associated with immediate paraplegia: total unprotected aortic clamp time ($P = .03$) and total aortic clamp time ($P = .04$).

Mortality rate. The overall operative mortality rate for the efficacy analysis group was 7.6% (11 patients).[23] This rate consisted of six 30-day deaths (4.1%) and five in-hospital deaths beyond 30 days. Thirty-day mortality rates were 5.3% (four patients) and 2.9% (two patients) for CSFD and control groups, respectively ($P = .68$). The operative mortality rate for patients with deficits was 45.5% (5/11) in contrast to 4.5% (6/134) for those without deficits ($P = .0003$).

DISCUSSION

The rationale for CSFD during TAAA repair is on the basis of experimental data that show: 1, CSF pressure increases during aortic clamping; and 2, reduction of CSF pressure improves spinal perfusion pressure.[24-28] Although the report by Murray et al[5] did not show any improvement with CSFD treatment, most retrospective comparative clinical reports[15-17,29] have suggested that CSFD may be beneficial. However, limitations in these reports, including heterogeneity of study groups, use of historic controls, and use of concomitant protective methods, make it difficult to specifically evaluate the contribution of CSFD to improvements in outcome.

In 1990, Crawford et al[18] reported a randomized trial that evaluated intraoperative CSFD during extent I and II TAAA repairs. Of 98 total patients, 46 (46.9%) underwent CSFD and 52 (53.1%) served as controls. Overall, 31 patients (31.6%) had paraplegia or paraparesis develop: 14 in the CSFD group (30.4%) and 17 in the control group (32.7%; $P = .8$). Factors associated with neurologic deficits included advanced age, extent II repair, increasing cross-clamp time, and postoperative hypotension. Although CSFD did not reduce deficits, the Institutional Review Board only allowed 50 mL of drainage during this study, which may have precluded any potential benefit.

In 1998, Svensson et al[13] reported a randomized trial with 33 patients in two centers. All patients had extent I or II TAAAs. Seventeen patients underwent CSFD and intrathecal papaverine hydrochloride treatment, and 16 patients served as controls. Other adjuncts, including LHB and active cooling, were used inconsistently in the two groups. There was a trend toward higher preoperative risk in the control group. For example, the control group had more emergent and urgent cases (7/16; 44%) than did the CSFD group (4/17; 25%). This difference did not reach statistical significance because of the sample size. Similarly, the control group showed a strong tendency toward more severe symptoms at presentation. Constant pain, life-threatening acute dissection, or shock were present in 56% of patients in the control group versus only 35% in the CSFD group. Neurologic injuries occurred in two patients in the CSFD/papaverine hydrochloride treatment group (11.0%) and in seven patients in the control group (43.8%; $P = .06$,

with Fisher exact test). Although the authors concluded that the combined use of CSFD and intrathecal papaverine hydrochloride was beneficial, the impact of CSFD alone is difficult to interpret.

This randomized trial focused solely on CSFD and its impact on neurologic deficits. The reduction in deficits was significant in both the intent-to-treat and efficacy analyses. In the latter, the CSFD and control groups were well matched with respect to established risk factors for paraplegia. All other adjuncts were used consistently in both groups, and there were no limitations in the amount of CSF that could be drained in obtaining target CSF pressures of 10 mm Hg or less.

We recently reported paraplegia rates of 3.9% for extent I repairs and 8.2% for extent II repairs.[3] The apparent increase in deficits in the control group (13%) relative to our previous data is difficult to explain but may be related to a more intensive focus on neurologic status during this prospective study. Nevertheless, the paraplegia rates in the control and CSFD groups are substantially lower than those reported in the other two randomized trials[13,18] and compare favorably with previous comparative retrospective studies (range, 6% to 22% in controls and 0% to 9% with CSFD), many of which include less extensive aneurysm repairs.[5,11,16,17]

Recent reports have described isolated cases in which patients with delayed paraplegia after TAAA repair underwent successful treatment with CSFD.[30-32] In a retrospective review, Safi et al[33] reported neurologic improvement after initiation of CSFD in eight patients with delayed deficits. During our study, CSFD was initiated in eight of nine control patients (89%) who had postoperative deficits. Neurologic function did improve in four of these patients (50%), but improvements occurred gradually, in contrast to the immediate resolution reported by other investigators. Improvement also occurred in the one patient who did not have a CSFD catheter placed after development of a deficit (Table III). Furthermore, all patients in whom deficits developed were immediately treated with a multimodality approach that included judiciously raising blood pressure, optimizing oxygen delivery, and administering intravenous steroids, mannitol, and naloxone hydrochloride. This immediate initiation of multimodality treatment makes it impossible to attribute subsequent recovery to any individual maneuver. Although we have not personally encountered immediate restoration of neurologic function after initiation of CSFD in patients with delayed onset paraplegia, the devastating nature of spinal cord injury combined with the potential for benefit suggest that it is appropriate to insert a CSFD catheter in these patients.

Several limitations of this study require discussion. Blinding the surgical team to treatment group was not feasible because CSFD requires active management during and after operation. A blinded examiner to perform postoperative neurologic assessment, however, would have improved this aspect of study design.

Insertion of a CSFD catheter in patients in the control group (without draining fluid) may have provided a more pure control group. Monitoring CSF pressure in both CSFD and control patients would have provided interesting comparison data and may have further enhanced our understanding of relationships between aortic clamping, LHB, CSFD, and CSF pressures. However, because this was not the focus of our study, CSF pressure data were not collected prospectively at predetermined time points in the experimental group and catheters were not placed in patients in the control group. Although rare, complications related to these catheters can be devastating, and the exposure of patients to risk without potential benefit was not justifiable.

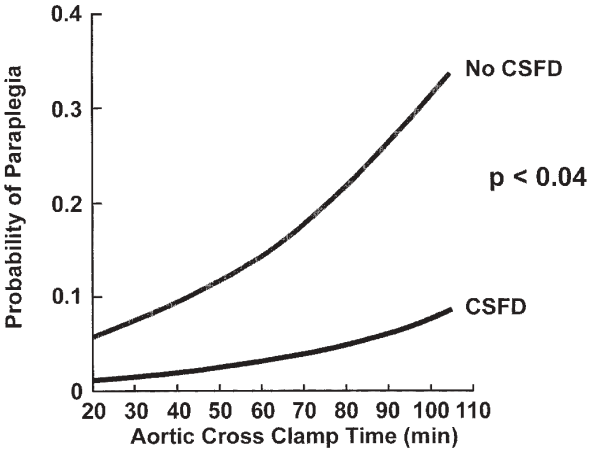

Fig 2. Logistic regression curves show reduction in risk of paraplegia or paraparesis associated with CSFD.

The scoring system used in this study was also used during the previous randomized trial in our institution.[18] Scoring early postoperative lower extremity function is often difficult, especially in patients with cardiac, pulmonary, and other neurologic complications. The ability to stand and walk cannot be assessed until patients are hemodynamically stable, are extubated, and have a satisfactory mental status. The use of ambulation as a measure, however, is important when quantifying a patient's degree of disability. The scoring system recently used by Svensson et al[13] focuses more on straight-leg raises and seems well suited for use throughout the postoperative course.

Although this trial clearly shows the benefit of CSFD during the repair of extent I and II TAAAs, the results cannot be extrapolated to the repair of less extensive aneurysms. There is currently no clinical evidence that show that CSFD prevents deficits during the repair of descending thoracic and extent III or IV TAAAs.

Finally, patients who underwent CSFD did not have improved survival rates. The study confirmed the established association between paraplegia and death[1]; the mortality rate was 10 times higher in patients with deficits than in those without. A substantial reduction in paraplegia should ultimately also reduce mortality rates. The demonstration of whether CSFD significantly reduces early or late mortality rates requires a larger study.

Ischemic spinal cord injuries are the result of complex interactions between several factors: perfusion and oxygen delivery, local metabolic rate and oxygen demand, reperfusion injury, and failure to maintain microcirculatory flow.[34] Therefore, although CSFD provides spinal cord protection, the risk of neurologic deficit cannot be portrayed as a simple balance between CSF pressure and distal aortic pressure. A more appropriate model—the ischemic time versus deficit risk curve introduced by Svensson and Loop[35] in 1988—has been used to illustrate the efficacy of various adjuncts. Techniques that reduce the risk of paraplegia shift the curve to the right (Fig 2), which corresponds to a reduction in risk for a given ischemic time. Conversely, factors that contribute to spinal cord injury shift the curve to the left. In addition to use of this model to show the benefit of CSFD, we have used the curve to illustrate the protective effect of LHB.[2] In the recent report by Svensson et al,[13] the relative effects of active systemic cooling, CSFD, and intrathecal papaverine hydrochloride treatment were illustrated as progressive rightward shifts of this curve. As the intricacies of ischemic spinal cord injury continue to be elucidated, this flexible conceptual model can be adapted to show the impact of newly recognized risk factors and preventive strategies.

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